Innovative Techniques in Road and Rail Construction on Expansive Soils

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Abstract
Expansive soils are highly problematic because of their nature of soils to undergo large volumetric change due to variations in the moisture content. These soils cover approximately 20% of total land area in India. Changes in volume resulting from variations in moisture in expansive soils and expansive soil subgrades cause damage to structures, highway pavements and other civil engineering infrastructure. This paper deals with the properties of black cotton soils or "regur" soils found in India which are expansive in nature. The paper presents a summary of technologies used to identify, test and treat expansive soils. The paper also discusses geological, mineralogical and physical properties of expansive soils along with categorization of technologies and testing methods with respect to applicability in Highway Engineering. The experimental results of different reports and research papers have been examined and summed up in this paper to suggest multiple remedial techniques in order to overcome the problems posed by expansive soils and to develop economic methods in road and rail construction.

Keywords: *Expansive Soils, Highway Pavements, Regur, Highway Engineering, mineralogical*

I. INTRODUCTION

Soil characteristics play a vital role for any construction. Expansive soils are problematic in nature due to their tendency to swell in presence of moisture and to shrink in moisture absence. Chen (1988) describes expansive soils as soils which swell or increase their volume when they imbibe water [1].An underestimation of these features may lead to a situation wherein the measures proposed prove inadequate or totally ineffective. The expansion of soils leads to structural damages which include damage in pavements, canal linings, bridge abutment and rupturing of pipelines. Cracks in beams, columns and flooring in buildings are very often found.

Gourley (1994) found the approximate losses that occurred in different regions. In United States, expansive soils cause $2.3 billion in damage to structures which is equal to twice the damage from floods, hurricanes, tornados and earthquakes combined. ASCE estimates that $1/4^{th}$ of all homes in U.S have some damage due to expansive soils. These soils are generally identified by direct correlation of swelling characteristics with index properties and by mineralogical study. The direct properties include swell pressure, swell potential and FSI.

This paper deals with the technologies used to identify, test and treat expansive soil. The experimental reports of different papers have been examined and summed up to develop economic way in road and rail construction.

II. PROPERTIES OF EXPANSIVE SOIL

In India the expansive soils, also called black cotton soils, majorly cover Deccan Plateau. The black soils are grouped under tropical black earths of soil group of the generic classification. Expansive soils are distinguished by their properties and conditions of formations (E.A. Sorochan 1989). The igneous rock breaks down through chemical weathering, resulting in clays and also allows the atoms to re-crystallize. These form Silicon-Tetrahedron sheets and Aluminium-Octahedral sheets. Kaolinites and Montmorillonites are the result of such re-crystallization [19].

The black soils are usually deficient in nitrogen, organic matter and sometimes also in phosphoric acid [22]. The presence of humus, organic iron and aluminium compounds are the major reasons for the black color. The black soils are classified as shallow black soils and deep black soils. The shallow black soils have low fertility; black color and coarse texture while deep heavy black soils are highly clayey and unworkable during rainy seasons.

The expansive soils of India fall under A7 group of USPRA classification system in which the sub groups are given by group index method [19].

III. METHODS FOR IDENTIFICATION OF EXPANSIVE SOILS

A. Subsurface Exploration:

For identification of soils, the most common method include subsurface exploration which further includes preliminary exploration and detailed exploration. This provides an idea of soil classification. Recently remote sensing technique has come into picture.

*1) **Visual Exploration**:*

The process is carried out based on color, texture and observations made at the field. The field identification of expansive soils can be done by observing the cracking pattern of the surface of the soil in summer seasons but in other seasons detailed study is required.

*2) **Remote Sensing Techniques:***

Presence of expansive soil increases cost and time for many civil engineering construction projects. Identification of the expansive soils and rocks using remote sensing, which involves less ground visits, should be useful. The identification of a few training samples is the first phase of remote sensing investigation. Then a signature is developed which can represent the training samples. Identification of expansive soils is thereafter tried using the supervised classification technique, following the maximum likelihood decision rule. Success and applicability of one or the other of the methods depends upon the nature of data structure, uniqueness of the signature, statistical distances between the signatures, nature of information class being sought, spectral bands used etc. All the three groups of spectral bands - visual, infra-red and microwave- have been applied for the investigation. The final result of classification appears in the form of a classified map.

B. Swelling Characteristics:

Since the expansive soils have the unique property of swelling, they exhibit the characteristics of swell pressure and swell potential. Swell potential is defined as the ratio of increase in thickness to the initial thickness of the clay specimen, written as

$$S\% = (\Delta H/H)*100 \qquad - (1)$$

By free swell method, swell pressure (p_s) is the pressure required to bring back or compress a swollen specimen to its initial void ratio. The swell pressure has also been defined by different surcharges method and constant volume method.

C. Mineralogical Study:

For the proper categorization of soil, different tests are conducted. The simple field tests include free swell test, load expansion test and dehydration test. Mineralogical study is also done by XRD [X-Ray Diffraction] method and Electron Microscope Resolution [EMR]. The use of EMR is not at field level due to its high cost of use.

*1) **Simple Lab Test***

*a) **Differential Free Swell Test**:*

In this method, soil fraction passing 425um sieve is oven dried at a temperature of 105 degrees centigrade. Then 10 grams of this soil is poured separately into two graduated cylindrical glass jars of 100 ml capacity. One contains distilled water while other kerosene. Both the cylinders are left for 24 hours and the final volumes are noted. The FSI is calculated (HOLTS & Gibbs 1956) as

$$FSI = (V_w - V_k) / V_k \times 100 \qquad - (2)$$

Where V_w and V_k= volume of the soil in water and kerosene respectively.

*b) **Load Expansion Test:***

This test is done to measure the change in volume from remolded condition to the air dried and saturated condition.

Two identical specimens (undisturbed or remolded) are taken in the "fixed ring type consolidometer", at desired density and water content. The specimens are allowed to dry in air till shrinkage limit. Volume of one of the specimens is measured by immersing it in mercury while other is loaded in the consolidometer. The change in volume is recorded.

*2) **Specialized Test:***

Under Differential Thermal Analysis (DTA) the soil is heated for the chemical reactions to occur. The reaction at different temperatures, depending on characteristics of mineral, provides the idea of level of expansive nature of soil.

The X-Ray Diffraction(XRD) method is used to determine the rough idea of thickness of minerals present and thickness of molecular water layers on the particle surface [12].In order to determine the interatomic distances and rearrangements of atoms in crystal, diffraction of X-ray with wavelength 1^A is employed. Inference patterns are photographed ultimately measured. The comparison of the measured distances to various diffraction lines with the diffraction data of known minerals is done.

IV. ROADAND RAIL CONSTRUCTION ON EXPANSIVE SOIL

Since the beginning of rail-road tunneling, in the middle of 19^{th} century, the swelling clay soils have caused tunnel collapse, which has ultimately resulted in considerable additional costs along with delays [Angnostou, 1992, 1995, Wittkle, 1978]. In Norway, 75% of the cost of the extra reinforcement for tunnels is associated with swelling clay, as stated by Selmer-

Olsen (1989). The maintenance costs for roadways on expansive soils are approximately 10 times greater than for the same type of pavement constructed on a suitable, non-expansive subgrade [13].

The various types of road pavement failures of roads include corrugations, cracking, depressions, edge defects, patching, polishing, potholes, roughness, rutting, shoving, stripping and raveling.The construction of rigid pavements has proven unsuccessful due to cracking as a result of subgrade expansion; however, flexible pavements require effective impervious base, sub base or a membrane below the surface (Halliburton 1972).

There are many practices which can be used to test the pavement subgrade before the final seal is placed like Proof Roll and Clegg impact value test. Testing of pavement strength may be divided into non-destructive and destructive testing. (Snethen,1979).Deflection testing is the most common form of non-destructive testing carried out on a road pavement which assesses the strength of pavement by measuring the response of the pavement to a loading. Mooney et.al (2000) has stated that destructive testing is often necessary for determination of true cause of a pavement failure.This is because non-destructive testing often cannot provide all necessary adequate information to identify failure mechanism.

V. SUBGRADE TREATMENT TECHNIQUES

According to Perry and Little (2002), the majority of treatment methods currently employed in the field has been around since 1960. The few of the popular treatments are

A. Replacement:

Das (2004) has given top priority to replacement of expansive soil with a less expansive material during the construction of foundation, while the current researchers rate replacement as the last option. However in the presence of ample depth, preference is still given to replacement method.

1) Sand Cushion Method:

The concept of bulking of aggregate is utilized in this method. The entire depth of expansive clay stratum or a part of it, depending on thickness, is replaced by sand. Then it is compacted to desired density and thickness. It is known that swelling pressure varies directly to density of sand layer and inversely to thickness. Hence sand cushions are formed in their loosest state to avoid excessive increase in swell pressure.

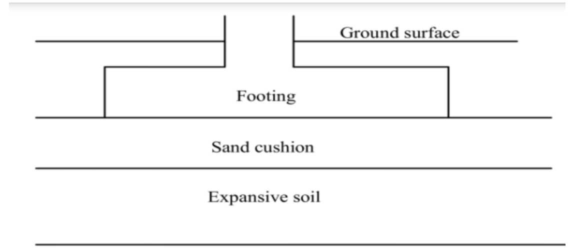


Fig. 1 Sand Cushion Technique

2) Cohesive Non Swelling Layer:

Katti (1978) finds that cohesive forces are developed up to a depth of about 1-1.2m, with saturation of expansive soil. This cohesive force helps to counter heave in soil beneath, even though the soil within the zone itself swells. The present trend of replacement has been shifted to cohesive non swelling material.

In CNS layer technique, around 1 to 1.2m top layer of expansive soil is replaced by CNS-soil layer. Actually it is necessary to conduct large scale tests for determination of optimum thickness of CNS layer. Gravel is a CNS material. Mechanically stabilized mix (MSM), recommended by Katti (1996), is placed on top of the CNS cushion to make soil strong enough to bear load.

B. Moisture Barriers:

Installation of vertical moisture barriers is one of the successful methods for minimizing differential movement of a road pavement constructed on an expansive clay subgrade. This method is already being used across the United States, Australia (Victoria) and in other countries too. In most cases, replacement is considered to be cost effective, but in case of rail and road construction, replacement method is cost prohibitive too.

The experiment results of TxDOT (instrument) for various methods of minimizing damage by encapsulating clay with impermeable fabric suggests that vertical moisture barrier proves to be successful method, when installed in the shoulder of the pavement. For this experiment, both horizontal and vertical barriers were used. [13] However this technique of moisture barriers is highly expensive therefore it is reserved for major highways. The technological investigations in Northern Victoria (Australia) have resulted in cost-efficient moisture barrier which can be adopted in local roads (Evans et al, 2004).The vertical barriers stop the seasonal lateral moisture migration through the subgrade, beneath the pavement (Picornell & Lytton, 1986). The barrier must extend at least till active zone (depth of cracking) for effective reduction in moisture migration.

The use of latest technologies and devices like Troxler Sentry 200-AP, could be installed to evaluate the moisture measurement inside and outside of vertical moisture barriers for more reliable data [13].

C. Cement:

The replacement of certain percentage of expansive soil with Ordinary Portland Cement (OPC) shows astonishing results. The percentage of soil removed could be 8%, 10% or 20% depending on various physical and geotechnical factors at the site. FSI, swelling pressure and swelling potential decreases significantly.

The use of GGBS (eco-cement) in expansive soil stabilization is a new process in geotechnical field (AniculaesiMircea et al). The laboratory tests report that the replacement of expansive soil with cement and GGBS in the ratio of 1:1 improves the shear strength and decrease in compressibility will be noticed.For practical implications, this technique requires high cost input.

D. Fly Ash:

Fly ash is a waste material, obtained from burning of coal in Thermal Power Plants. The disposal of fly ash is a major challenge for power plant authorities. It is a hazardous material for atmosphere because of its low specific gravity and is non-plastic in nature. One of the disposal techniques includes the stabilization of expansive soils using fly ash [8].

Fly ash can be used as a stabilizer for soil due to its pozzolanic effect or due to self-hardening property under favorable conditions of moisture and compaction (Rollings, 1996). Studies have been carried out by Phanikumar and Sharma (2004) on the effect of fly ash on engineering properties of expansive soil [23].The samples of ash-blended expansive soil with fly ash contents of 0,5,10, 15 and 20% were used. The penetration resistance of the soil mixed with fly ash was determined from penetration tests (ASTM 1999, D1558). The index properties of the test sample are mentioned below.

The result was reduction in plasticity characteristics and FSI by 50% on addition of 20% fly ash. The hydraulic conductivity (k) decreased with increase in fly ash content. Swell potential and swell pressure decreased to 50% on 20% addition of fly ash, but above 20% no considerable change has been observed. Compaction behavior, penetration resistance, undrained shear strength were examined.

Table 1 : Properties of Index of Expansive Soils and Fly Ash

Property	Standard designation	Expansive soil	Fly ash
Specific gravity	ASTM D854-02	2.72	2.1
Liquid limit (%)	ASTM D4318-00	80	—
Plastic limit (%)	ASTM D4318-00	28	—
Plasticity index (%)	ASTM D4318-00	52	NP
Gravel (%) (>6.20–4.75 mm)	ASTM 98 D422-63	0	0
Sand (%) (4.75–0.075 mm)	ASTM 98 D422-63	7	0
Silt (%) (0.075–0.002 mm)	ASTM 98 D422-63	24	92
Clay (%)(<0.002 mm)	ASTM 98 D422-63	69	8
Free swell index (FSI)	ASTM D5890-02	250	Nonswelling
USCS classification	ASTM D2487-00	CH	Nonplastic

Table 2 : Effect of Fly Ash on Index Properties, Swelling, Compaction Behavior and Hydraulic Conductivity.

	Fly ash content				
Property	0	5	10	15	20
Liquid limit (%)	80	77	75	73	70
Plastic limit (%)	28	31	35	40	44
Free swell index	250	200	165	140	125
Swell potential (%)	10.8	8.75	7.2	6.0	5.5
Swelling pressure (kPa)	90	72	60	50	45
Optimum moisture content (%)	40	38	35	33	31
Maximum dry unit weight (kN/m^3)	13.75	13.91	14.05	14.19	14.30
Hydraulic conductivity, k (cm/s)	9.70×10^{-7}	Not tested	6.02×10^{-7}	Not tested	3.95×10^{-7}

Undrained cohesion (c_u) was calculated using Sanglerat (1972) relation between the penetration resistance and c_u;

$$Q_c = N_k c_u + P_o \qquad - (3)$$

where Q_c = penetration resistance; c_u = undrained cohesion; P_o = total overburden pressure; and N_k= penetration constant. The graph between measured c_u with percentage of fly ash and watercontent is drawn.

Fig 2: Variation of Measured c_u with Percentage

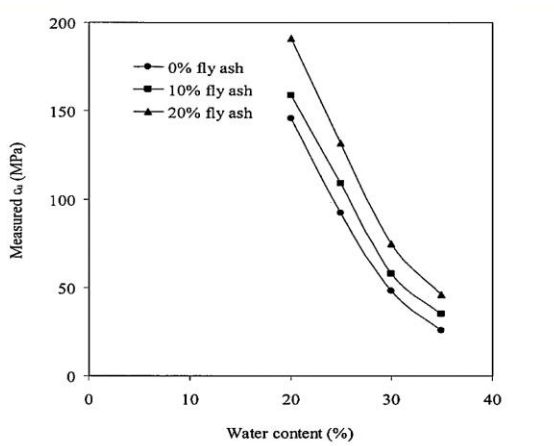
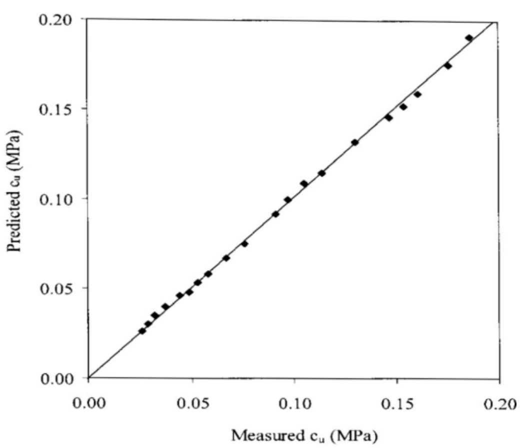


Fig 3: Correlation of Measured and Predicted c of Fly Ash and Water Content



E. Use Of Lime:

Expansive clay stabilization with chemicals has been found to reduce swelling and influence Free Swell Index FSI, swelling pressure and swell potential. Among all additives, lime is one of the economical and effective additives. It reduces swell potential meanwhile increases workability and strength. Lime content of 4% can be added to expansive soil as beyond 4% results in increased swell potential and swelling pressure (Phanikumar). Experimental study on effect of lime on Index (FSI), swell potential, swelling pressure, consolidation characteristics, compaction characteristics and strength behavior [14,8].

As experimental authentication, tests have been conducted (Phanikumar) on the sample of expansive soil 1.2m depth, having FSI of 165% and using unslaked lime as additive. The other details of the sample include

Table 3: Index Properties

Specific gravity	2.72
Liquid limit (%)	100
Plastic limit	27
Plasticity index	73
Gravel (%) (>6.20–4.75 mm)	0
Sand (%) (4.75–0.075 mm)	7
Silt (%) (0.075–0.002 mm)	24
Clay (%) (<0.002 mm)	69
Free Swell Index (FSI)	250
USCS classification	CH

The initial water content (wi %) and the dry unit weight of the soil were kept constant at 0% and 13 KN/m^3 respectively. Lime concentration (by dry weight of expansive soil) was varied as 0%, 2%, 4% and 6%. Evaluation of two test samples was done and the average was reported.

Free Swell Index (FSI) Test,one dimensional swell-consolidation tests,proctor compaction tests and unconfined compression tests were done and the results were obtained.

1) Effect of Lime on Plastic Index:

The effect of lime on Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI) of the expansive soil is shown in fig3. Decrease in PI takes place due to increase in PL and decrease in LL with increase in lime content. At a lime content of 4%, a maximum reduction in PI of 36% was obtained. No further change in PI was observed when the lime content was increased beyond 4%.

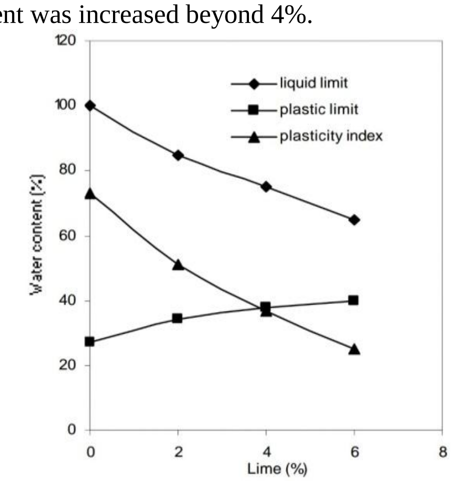


Fig. 4: Effect of Lime on LL, PL and PI

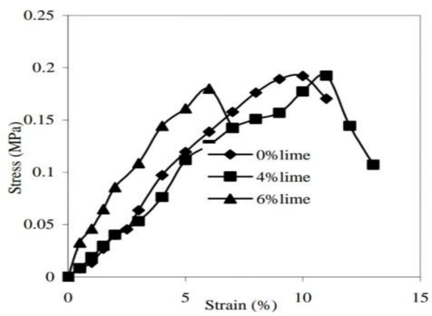


Fig. 5: Effect of Lime on Stress-Strain Behaviour

2) Lime Effect on Swelling Behavior:

With increase in lime content, Free Swell Index (FSI) decreased. This is because of decrease in surface activity with flocculation, which reduces FSI. FSI increased, when lime content was increased beyond 4% and reduced by 27% at 4% lime content. Figure 6 shows the rate of heave for varying lime contents (0%, 2%, 4% and 6%). The rate of heave is presented in plots showing time (minutes) on X-axis and heave (mm) on Y-axis. The untreated expansive clay (0% lime) attained a heave of 5.4 mm (at a swell potential of 27%) in three days. Due to the development of cementitious products, the sample could not be compressed even at higher compressive loads so swelling pressure could not be measured at a lime content of 6%.

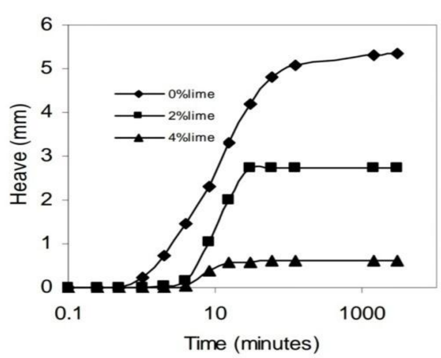


Fig. 6: Effect of Lime on Rate of Heave

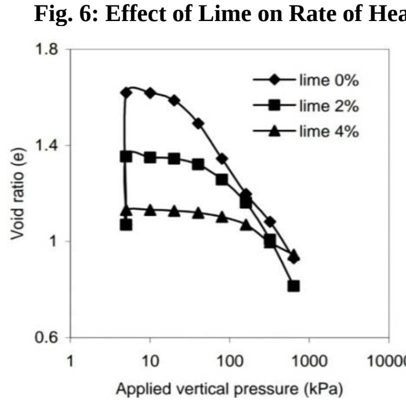


Fig. 7: Effect of Lime on e-log p Curve

F. LSPI:

Chen (1988) describes a technique called Lime Slurry Pressure Injection (LSPI), used for minimizing swelling of soils in pavements. In LSPI, lime slurry is injected into drill holes under a pressure of $15 kg/cm^2$. The lime slurry penetrates into the fissures in the soil mass to a depth around 8-10 feet. The ultimate result includes reduction in volumetric change, control of the soil water content and increased in soil strength [18].

The effectiveness of LSPI depends upon network of fissures. Hence, extensive network of fissures is required for this technique to be more effective else, lime cannot penetrate into relative impermeable soil to an appreciable distance.

VI. BEST PAVEMENT PRACTICE - RESULTS AND DISCUSSION

The use of mechanical alterations seems to be infeasible for large highway or rail project. The only way is chemical alteration done using cement, lime, fly ash or other material; depending upon the use. The technique of fly ash uses the waste materials and hence it is environmentally friendly too.

As this paper focuses on road and rail construction on expansive soil, the latest trend has been discussed in this topic. Currently, the use of *geo-synthetics* is considered to be most effective way of achieving a variety of outcomes. The main reason behind this includes availability of a variety of geo-synthetic with specific material properties.

Tutumuler and Kwon (2005) found that geotextiles and geo-grids are extensively being used in U.S.A as a subgrade restraint. The study on tri-axial geo-grid performance (Qian et al, 2010) reports that tri-axial geo-grid provide more uniform resistance to material movement, reduced pavement displacement and vertical stresses rather than uniaxial and biaxial grids. The limitation includes that most geo-grids do not provide moisture barrier, drainage or particle separation.

The use of rigid pavements has proven unsuccessful on expansive soils; so flexible pavement comes into role. However flexible pavement requires effective impervious base, subbase or a membrane below the surface (Haliburton,1972). For flexible pavement to be achieved, documented empirical or mechanistic materials is suggested.

VII. FUTURE SCOPE

The stated outcomes from the present review paper indicates that further research could be undertaken in the following areas (with respect to clays) for construction of pavements and rails on expansive soil-:

- Longer term testing of stabilization process.
- To determine the active depth of expansive soils.
- Advantages of performance based testing over traditional testing.
- Clays classification using various methods.
- The use of polymer modified seals on stabilized pavements to minimize reflective cracking.

VIII. CONCLUSION

Investigation of expansive soil is not only necessary for exploring the engineering properties of expensive soils and discussing the expansion mechanism but also indispensable as to the improvement and reinforcement of expansive soils and the discussion of new soil research techniques and methods. As the Indian government aims for smart cities and development of villages, the enhancement in transportation systems is an indispensable part of this program. During the application of expansive soils in the construction and employment of embankment, the peculiarity is influenced by both the nature of the denudation and deliquescence of expansive soils.

IX. ABOUT THE AUTHORS

Dr. B R Phanikumar - PhD, Senior Professor, Civil Engineering, VIT University, Vellore · Division of Structural and Geotechnical Engineering. 31 publications, 1.55 k reads and 225 citations has been observed as per research gate on his various papers.

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